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Sedentary Behaviour and Obesity in a Large Cohort of Children

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Abstract

The purpose of this study was to examine the association between sedentary behaviour and obesity among 12-year-old children, while adjusting for moderate-to-vigorous physical activity (MVPA) and other potential confounding variables.

Cross-sectional analyses were carried out with data from 5434 children who participated in the Avon Longitudinal Study of Parents and Children (ALSPAC). Fat mass was derived using dual x-ray emission absorptiometry (DXA), and height and weight measurements were used to calculate body mass index (BMI; kg/m^2). The children wore an accelerometer for seven days. The cut points for sedentary behaviour and MVPA were ≤199 cpm and ≥3600 cpm, respectively. Logistic regression analyses were performed to estimate odds ratios (OR), adjusting for potential confounders of physical activity that included gender, social factors, early life factors and maturation.

The minimally adjusted association between sedentary behaviour and obesity was positive, OR=1.18 (1.08, 1.28). After adjusting for the series of potential confounders of physical activity the positive association remained, OR=1.32 (1.14, 1.53). The crude association between 15 minutes of MVPA per day and obesity was negative, OR=0.54 (0.48, 0.62). When 15 minutes of MVPA per day was additionally controlled for in the models, the positive associations between sedentary behaviour and obesity were negated.

Sedentary behaviour was positively associated with obesity in the 12-year-old children, but this association was not independent of MVPA; low levels of MVPA among the sedentary children increased the odds of obesity. These finding support the importance of specifically engaging in MVPA during childhood to reduce the prevalence of obesity.

Introduction

The study of sedentary behaviour and its association with obesity during childhood and into adolescence is growing, with cross sectional and prospective studies having examined the association (1). The results from these studies are inconsistent, with some reporting strong positive associations (2) and others finding no associations (3).

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Disclosure Statement

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When studying the association between sedentary behaviour and obesity it is important to distinguish sedentary behaviour from low levels of physical activity (4). Non-exercise activity thermogenesis (NEAT) encompasses low levels of physical activity (5), whereas sedentary behaviour refers to activity in which the work of the large skeletal muscles involved in habitual movement and postural control is very limited. Sitting is the most prevalent sedentary behaviour (6).

There is a tendency for time spent sedentary to increase from early to late adolescence and boys, despite engaging in moderate-to-vigorous physical activity (MVPA) for longer durations, are typically more sedentary than girls (7,8). Furthermore, when maturing from adolescence into adulthood individuals tend to spend even more time engaged in sedentary behaviour (9). The importance of these patterns are of much concern, since high levels of sedentary behaviour have been shown to increase the risk of obesity-related health problems, including type II diabetes, cardiovascular disease, certain cancers, and various metabolic risk factors (10–13).

Recommendations have been proposed for adults and children to engage in MVPA throughout the day, in part to address the obesity-related health problems cited above and to improve cardiorespiratory fitness (CRF) (14). Yet there is evidence to show that sedentary behaviour is a risk factor for obesity (15,16) and an elevated metabolic risk profile, independent of MVPA (15,17). It is even possible that sedentary behaviour may be independently associated with CRF, since MVPA does not explain all of the variance in CRF (18). These studies indicate that current physical activity recommendations may be incomplete and a specific recommendation for the time spent sedentary may be required.

In order to determine the independent effects of sedentary behaviour on health outcomes, sedentary activity must be measured with accuracy and precision. Television viewing time has been used as an indicator of sedentary behaviour in previous studies (2,15) and although television viewing is the primary sedentary activity of adolescents, it is not the only sedentary activity in which they participate (19). Accelerometry can be used to measure the broad scope of sedentary behaviours in which individuals participate and may provide a more accurate and precise measure of sedentary behaviour (17,20).

The purpose of this paper was to determine current levels of sedentary behaviour in a sample of children residing in the UK, using accelerometry, and to determine the association between sedentary behaviour and the odds of being obese, defined by fat mass ascertained through the use of dual energy x-ray absorptiometry (DXA).

Research Methods and Procedures

Study Participants

The Avon Longitudinal Study of Parents and Children (ALSPAC) is a prospective birth cohort study. Baseline recruitment specified that pregnant women residing in the former County of Avon, in the United Kingdom, with an expected delivery between April 1991 and December 1992 were eligible for inclusion (21). A total of 14,541 pregnant women enrolled into the study at baseline. From the subsequent births, 11,952 children were invited to attend the 11-year research clinic for physiological and psychometric measurements. Only singleton children with complete accelerometer and body composition measures were included in the present study. Ethical approval for the study was obtained from the ALSPAC Law and Ethics Committee and the Local Research Ethics Committees.

Body Composition

Measures of height and weight were obtained at the 11-year clinic; the former was measured in bare feet with a Harpenden stadiometer (Holtain Ltd, Crosswell, UK) and the latter was measured using a Tanita body fat analyser and weighing scales (Model TBF 305, Tanita UK Ltd Middlesex, UK). Body mass index (BMI) was calculated by dividing weight (kg) by height (m^2). Fat mass and lean mass were assessed using a Lunar Prodigy DXA scanner (GE Medical Systems). The top 10% of fat mass (adjusted for age, height and height^2 to take into account differences in stature) defined obesity, and this was derived from the entire sample of children who attended the 11-year clinic. The top 10% for fat mass represents a clinically relevant level of excess fat mass, since the boys and girls had at least 34% and 39%, respectively, of their body weight as fat at this definition. Overweight was defined by the age-specific international cut points, which corresponded to a BMI of 25 kg/m^2 at 18 years of age (22).

Physical Activity and Sedentary Behaviour

Physical activity and sedentary behaviour were assessed objectively. The children wore an accelerometer (MTI Actigraph AM7164 2.2, Fort Walton Beach, FL) around their waist, at the right hip, for seven days during waking hours, removing the accelerometer for bathing, swimming, or other water activities. Children recorded the times spent swimming or cycling on a time sheet, because the accelerometer does not provide an accurate account of non-weight bearing activities. However, no children were excluded who reported cycling or swimming, since previous sensitivity analyses revealed no differences in the results with and without their inclusion (23). The accelerometers were initialised to collect data via one-minute epochs, and total physical activity was expressed as the average counts per minute (cpm) over the period of valid recording (minimum of 3 days, 10 hours per day) (24). It was previously shown that there was no great variation in the mean times of accelerometer wear during the week and weekend (13.1±0.9 hours and 12.3±1.2 hours respectively) (24) and so reporting the absolute time spent sedentary and engaged in MVPA was deemed to be appropriate. A sub-group of 246 children participated in a calibration study to determine a cut point for MVPA, which was subsequently defined as ≥3600cpm. The protocol involved children wearing an accelerometer and an indirect calorimeter (Cosmed K4b^2; Cosmed, Rome, Italy) while lying down, sitting, slow walking, fast walking, playing hopscotch and jogging; the MVPA cut point was based on an energy expenditure of 4 METs (25). The macro used to determine the physical activity intensities did so in blocks of 200cpm and so sedentary behaviour was defined as ≤199cpm (24). This cut point is comparable to other accelerometer definitions of sedentary behaviour in children (20).

Confounders

Potential confounding variables, shown to be independently associated with obesity and physical activity in previous ALSPAC analyses (26–29), were controlled for in our current analysis, Table 1 provides the time scale of when these data were collected. Social class was determined via the occupation of the mother or father (lowest class was used if the parents' occupation status differed), which was recorded through the 32-week antenatal questionnaire. Five categories of class were identified using the UK 1991 Office for Population Censuses and Surveys criteria (30). Maternal education was also obtained from the 32-week antenatal questionnaire. Categories included none/Certificate of Secondary Education (CSE) (national school exam at 16); vocational, O level (national school exam at 16, beyond CSE); A level (national school exam at 18), or degree. Maternal smoking status during pregnancy was recorded on the 18-week and 32-week antenatal questionnaires. The 18-week antenatal questionnaire asked about the mothers' smoking habits during the first trimester and in the previous two weeks. The 32-week antenatal questionnaire determined the mothers' current number of cigarettes smoked per day. Maternal obesity (BMI ≥30kg/m^2) was determined from the pre-pregnancy weight and height, recorded by the mother, when enrolled into the study. The birth weight of the offspring was obtained from obstetric records and/or birth notifications; gestational age was estimated from the last reported menstrual period to the time of birth. The total time of television viewing per week for each child was reported by the mother in the 38-

month questionnaire. The mothers also noted their child's sleeping patterns, when completing the earlier 30-month questionnaire. The pubertal status of the children was determined when they were approximately 11-years old. The child's caregiver noted the development of pubic hair for boys and girls and breast development for girls (31) and only those completing this process within 16 weeks of receiving the questionnaire were included in our analyses.

Statistical Analyses

Descriptive statistics for the study variables were calculated for the total group and by gender. To determine if sedentary behaviour was related to obesity, we ran a series of logistic regression models, with social factors, early life factors and biological maturation incrementally adjusted for in chronological order. This allowed for the impact of each factor on the association between sedentary behaviour and obesity to be documented. The first model included sedentary hours per day and gender (there was no evidence of a gender interaction). Independent variables in the second model included all of the variables from the first model plus social factors (27–29): social class, mother's education, whether the mother smoked during pregnancy, whether the mother was obese, birth weight, and gestational age. The third model included all of the variables from the second model and whether the child watched more than 8 hours of TV per week at 38 months, and if he or she slept 10.5 or more hours per night at 30 months (26). The fourth model included all of the variables in the third model and pubertal status. A second series of multiple logistic regression models were analyzed with the addition of 15 minutes of MVPA per day to each of the four models to fully determine the independent association between sedentary behaviour and obesity. The 15 minutes of MVPA per day variable was calculated by multiplying the one minute of MVPA β coefficient by fifteen. The sample sizes vary between the models, due to missing questionnaire items, so the analyses were repeated using only participants with complete data and t-test were performed to compare those with complete data and those with missing data. All analyses were conducted using SAS (version 9.1).

Results

A total of 11,952 children were invited to the 11-yr clinic; 7,159 attended and 6,622 agreed to wear an accelerometer for one week. A total of 5,595 children provided valid accelerometry data. The 1,564 children with invalid accelerometry data were more likely to have a higher BMI and to be male, although these differences were small (24). A total of 5504 children (males n=2624) provided both body composition measures and valid accelerometry data. After excluding multiple births, our final sample consisted 5434 singleton children (males n=2590).

The characteristics of the children are detailed in Table 2. The mean age of the boys and girls attending the 11-year clinic was 11.8 (±0.2) years; the children hereafter will be referred to as 12-year-olds. There was a higher prevalence of overweight, defined by BMI, among the girls compared to the boys. The prevalence of obesity was slightly lower than the top 10% for fat mass definition that was determined from all the children providing body composition measures, indicating that obese children were less likely to adhere to the accelerometry protocol. Nonetheless the difference in the prevalence of obesity between genders was minimal and was very close to our definition. Data concerning pubertal status revealed a greater proportion of girls to be in later stages of development compared to the boys. The television viewing hours per week, at 38 months, were similar between genders. The majority of the children accrued at least 10.5 hours of sleep per night at 30 months; however, a greater proportion of boys than girls slept for less than 10.5 hours per night.

The accelerometry data describing time spent sedentary are presented in Table 3. Girls spent more time than boys engaged in sedentary behaviour, but only on weekdays. Time spent engaged in MVPA was greater among boys than girls, as was the total volume of physical activity expressed as total counts per minute (Table 3).

The results in Figure 1 show that the minimally adjusted odds of being obese were 1.18 (1.08, 1.28) times more likely for every hour spent sedentary per day among the 12-year-old children (model 1). This positive association was strengthened (OR=1.30 (1.16, 1.44), OR=1.35 (1.20, 1.51) and OR=1.32 (1.14, 1.53)) after adjusting for the social factors, early life factors and maturation in models 2, 3 and 4 respectively.

The crude association between 15 minutes of MVPA per day and obesity among the 12-year-olds yielded an OR of 0.54 (0.48, 0.62). When all the models were additionally adjusted for 15 minutes of MVPA per day, the previous positive associations between an hour spent sedentary per day and obesity at 12 years were negated; OR=0.99 (0.91, 1.09), OR=1.09 (0.97, 1.22), OR=1.12 (0.99, 1.27) and OR=1.09 (0.93, 1.28) for models 1 through 4 respectively (Figure 1).

A higher proportion of males, obese children and those born to mothers with the lowest education level had missing data (data not shown). Additional logistic regression analyses were performed using subjects who had complete data for all the confounding variables (n=2421), and the same patterns of association were found for all the models, with and without MVPA (data not shown). The patterns of association were also similar when BMI derived overweight and obesity were used as dependent variables (data not shown). Model 4 was repeated with the inclusion of lean mass as a covariate, and this had no effect on our results (data not shown).

Discussion

The odds of obesity in our sample of children increased per hour of sedentary behaviour. This positive association persisted after controlling for potential confounding variables, including age, sex, height, height^2, parental sociodemographic characteristics, maternal smoking, maternal obesity status, early life sleep and television viewing patterns, and pubertal development. However, when the four models that adjusted for these confounders were further adjusted for MVPA, the association between sedentary behaviour and obesity disappeared in each - indicating that the time spent engaged in MVPA is lower among sedentary children. This interpretation is supported by the negative correlation that exists between sedentary behaviour and MVPA ($r = -0.39$, $p<0.001$) in our sample.

Our findings are in contrast to a recent study involving a sample of European children, which reported that the positive association between sedentary behaviour (television viewing) and adiposity was independent of physical activity and other confounding variables (16). The difference in findings between the two studies may be due to self-reported television viewing hours being used as a proxy measure of sedentary behaviour, the use of BMI as a measure of adiposity or the adjustment for total physical activity and not specifically MVPA (16). These results support the need to specifically limit time spent engaged in sedentary behaviour in order to avoid excess adiposity. Whereas, our data support the need to engage in MVPA, as recommended (14), in order to reduce the prevalence of obesity and do not indicate that an additional recommendation for time spent sedentary is needed.

The accumulation of physical activity is widely believed to exert health benefits. More specifically, it is the intensity of physical activity accumulated that is of most importance. In a sample of Swedish adolescents, a positive association between television viewing and obesity was subsequently nullified upon adjusting for vigorous physical activity (VPA) in addition to other confounding variables (32). In a sample of Australian adults, breaks in sedentary time to engage in light intensity physical activity were shown to be beneficial in terms of waist circumference, BMI and metabolic risk factors, independent of total sedentary time and MVPA (33). These findings along with our results show that health outcomes are potentially improved by the whole spectrum of physical activity intensities, when physical activity is incorporated into sedentary lifestyles.

There is strong evidence that MVPA, and especially VPA, is positively associated with CRF in children (18). Perhaps the impact of MVPA on obesity in our results may be explained by an increased CRF and subsequent preferential fat utilization as a fuel through β oxidation. However, MVPA does not explain all the variance in CRF (18), and excessive sedentary behaviour, regardless of MVPA accumulated, may have been detrimental to the 12 year olds' CRF.

It is also possible that the independent effects of sedentary behaviour might well have remained, after adjustment for MVPA, for outcomes concerning metabolic risk. A recent review suggests that a loss of the thousands of intermittent muscle contractions (NEAT) throughout the day that occurs with sedentary lifestyles could invoke adverse metabolic consequences (6), and in adults there is evidence that sedentary behaviour is associated with metabolic risk factors independent of MVPA (17). Sardinha *et al*. reported that the time spent sedentary, measured through accelerometry, in 10-year-olds, was positively associated with insulin resistance (34), however MVPA was not adjusted for in their models. It has also been suggested that the independent positive association between sedentary behaviour (television viewing) and adiposity leads to adverse metabolic profiles in children as a consequence of the increased adiposity (16). Additional large population-based studies are needed to enhance our understanding of the associations between sedentary behaviour and metabolic risk factors in children.

A second theme of our results regards the time boys and girls spent engaged in sedentary behaviour. Our data are in contrast to previous studies that have noted that boys spend more time sedentary than girls (7,8). However, these studies used self-reported small screen recreation (SSR) as a proxy measure of sedentary behaviour. Recent data from the U.S. and Portugal that used accelerometry to assess sedentary behaviour among children and adolescents mirrored our results (34,35). Accelerometry data has consistently found girls to be more sedentary than boys.

There are limitations to our study. Our cohort represents a group of children of similar age in one place in one time, so our results may not be accurate for all populations. Also, the sample of children who provided valid accelerometry and body composition data had a slightly lower prevalence of obesity (below the top 10% for fat mass) compared to the entire sample who attended the 11-year clinic and this was more pronounced among the boys (Table 1). The definition of obesity used was thought to represent a clinically relevant level of excess fat mass, but levels below the top 10% for fat mass could also be associated with additional health risks. Similar results were found when BMI defined overweight was used as the dependent variable. More males, obese children and those born to mothers with the lowest education level had missing data and this should be taken into consideration when generalizing these results. However, when all the models were repeated for those with complete data, the patterns of association were almost identical. In terms of the minimal requirements for accelerometry wear – Fairclough *et al*. reported that the number of days required to obtain an accurate account of girls' physical activity was greater than what was needed for boys (36). However, we have shown previously that the minimal requirement of 3 days of wear, for boys and girls, provided an acceptable reliability coefficient, while ensuring good power (24). The use of a one-minute epoch is perhaps a limitation of our accelerometry data, since MVPA can potentially be underestimated. Our cut point for sedentary behaviour was similar to the Treuth *et al*. cut point (20). Although not an exact match, due to our macro determining the cut points in blocks of 200cpm, we feel our cut point is very representative of sedentary behaviour. It should be taken into consideration that the Treuth *et al*. cut points were determined from a sample of adolescent girls in the U.S. (20) and regardless of a calibration protocol, differences in cut points shall exist between populations.

In conclusion, the major finding of our study was that sedentary behaviour was positively associated with obesity, but this association disappeared when MVPA was taken into account. As we have shown previously, a lack of MVPA is associated with obesity among the 12-year-olds in our cohort (23). The current physical activity guidelines advocate MVPA for improving numerous health outcomes and do not specifically recommend limiting the time spent sedentary. Our data supports the need to engage in MVPA in order to reduce the prevalence of obesity during childhood.

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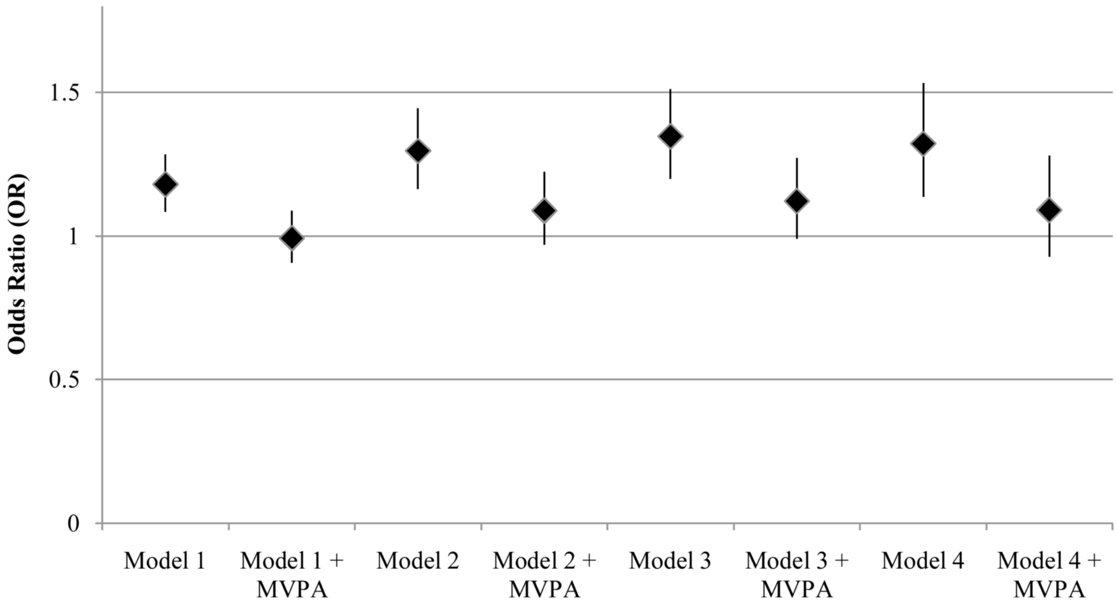

Figure 1.
Logistic Regression results for the association between obesity and sedentary hours per day, (+MVPA: additionally adjusting for 15 minutes of MVPA per day). Model 1 (n=5434) adjusting for gender; model 2 (n=4102) additionally adjusted for social factors; model 3 (n=3576) additionally adjusted for early life sleep and TV habits; and model 4 (n=2421) additionally adjusted for pubertal status

Table 1

time scale of data collection

Variable	Source	Time of Collection
Maternal Obesity	Self-report	At enrolment
Birth weight	Birth records	At birth
Gestation	Self-report & birth records	At birth
Maternal Smoking	Antenatal Questionnaire	18 & 32 weeks
Maternal Education	Antenatal Questionnaire	32 weeks
Social Class	Antenatal Questionnaire	32 weeks
Sleep Pattern	Infant Questionnaire	30 months
Television Viewing	Infant Questionnaire	38 months
Pubertal Status	Tanner Stage	11-year clinic
Obesity	DXA	11-year clinic
Overweight	BMI	11-year clinic
Physical Activity	Accelerometry	11-year clinic

Table 2

characteristics of the ALSPAC participants attending the 11-year clinic with valid accelerometry and body composition data

Variable	Total		Males		Females		P value[a]
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	
Age (years)	5434	11.8 (0.2)	2590	11.8 (0.2)	2844	11.8 (0.2)	0.28
Height (cm)	5434	150.7 (7.2)	2590	149.9 (7.1)	2844	151.4 (7.2)	<0.001
Weight (kg)	5434	43.5 (9.8)	2590	42.4 (9.5)	2844	44.5 (10.1)	<0.001
BMI (kg/m^2)	5434	19.0 (3.3)	2590	18.7 (3.2)	2844	19.3 (3.4)	<0.001
Birth weight (kg)	5100	3.4 (0.5)	2445	3.5 (0.6)	2655	3.4 (0.5)	<0.001
	N	Percent	N	Percent	N	Percent	
Obese[b]	506	9.3	236	9.1	270	9.5	0.64
Overweight[c]	1143	21.0	512	19.8	631	22.2	0.03
Pubertal Status[d]							
1	699	20.9	507	38.4	192	9.5	
2	1188	35.5	563	42.6	625	30.9	
3	908	27.1	196	14.8	712	35.1	
4	444	13.3	53	4.0	391	19.3	
5	109	3.3	3	0.2	106	5.2	<0.001
Missing	2086						
Mother Obese[e]	242	5.2	122	5.4	120	4.9	0.43
Missing	738						
Smoked During Pregnancy[f]	937	20.2	442	20.0	495	20.3	0.77
Missing	785						
Mother's Education[g]							
1	639	12.8	303	12.6	336	12.9	
2	417	8.3	216	9.0	201	7.7	
3	1800	36.0	854	35.5	946	36.4	
4	1334	26.6	642	26.7	692	26.6	
5	817	16.3	392	16.3	425	16.4	0.61
Missing	427						
Social Class[h]							
1	182	3.8	86	3.8	96	3.8	
2	1239	25.9	616	27.0	623	24.9	

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Variable	Total		Males		Females		P value[a]
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	
3 (nonmanual)	1303	27.2	622	27.2	681	27.2	
3 (manual)	1275	26.6	606	26.5	669	26.7	
4	643	13.4	288	12.6	355	14.2	
5	147	3.1	67	2.9	80	3.2	0.48
Missing	645						
TV viewing >8hr/wk[i]	1378	29.7	688	30.9	690	28.7	0.10
Missing	799						
Sleep <10.5 hr/d[j]	679	14.7	362	16.3	317	13.2	0.003
Missing	813						

[a] p values for male and female comparisons;

[b] Top 10% of fat mass adjusted for age, height, height^2 (derived from all the ALSPAC participants attending the 11-year clinic);

[c] Cole *et al*. International cut-points (22);

[d] Pubertal status determined by Tanner stage (1=least mature to 6=most mature);

[e] Self-reported height and weight at enrolment (obese = ≥30kg/m^2);

[f] Self-reported smoking at 18 and 32 weeks gestation;

[g] Mother’s education (1=none/CSE to 5=degree);

[h] Social class based on occupation of mother and father (1=high social class to 6=low social class);

[i] Parent reported television viewing hours at age 38mo;

[j] Parent reported sleep pattern at 30mo.

Table 3

time spent sedentary and engaged in moderate-to-vigorous physical activity (MVPA) as assessed by accelerometry

	Total		Males		Females		p value[a]
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	
Sedentary							
Minutes per day	5434	427.7 (66.4)	2590	417.9 (67.7)	2844	436.5 (64.0)	<0.001
Hours per day	5434	7.1 (1.1)	2590	7.0 (1.1)	2844	7.3 (1.1)	<0.001
Weekend Sedentary							
Minutes per day	4876	398.3 (86.8)	2361	398.2 (90.9)	2515	398.4 (82.8)	0.94
Hours per day	4876	6.6 (1.4)	2361	6.6 (1.5)	2515	6.6 (1.4)	0.94
Weekday Sedentary							
Minutes per day	5434	437.1 (70.4)	2590	424.9 (70.8)	2844	448.2 (68.1)	<0.001
Hours per day	5434	7.3 (1.2)	2590	7.0 (1.2)	2844	7.5 (1.1)	<0.001
MVPA (minutes/day)	5434	23.1 (15.2)	2590	28.4 (16.9)	2844	18.3 (11.7)	<0.001
CPM (Counts/min)	5434	604.7 (177.1)	2590	662.9 (185.3)	2844	551.7 (150.9)	<0.001

[a] p values for male and female comparisons